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"CARFAX" TRAFFIC INFORMATION SERVICE: an analysis of the characteristics of the ring system and receiver activation

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'CARFAX' TRAFFIC INFORMATION SERVICE: AN ANALYSIS OF THE CHARACTERISTICS OF THE RING SYSTEM AND RECEIVER ACTIVATION

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SUMMARY

The Report describes the development of a modified form of the original BBC proposal for a Traffic Information Service known as the 'ring' system. In the ring system, the motorist's receiver selects the strongest signal available from local transmitters by making use of the f.m. 'capture' effect in conjunction with an f.m. signalling system.

The Report concludes that the system should perform well in practice, with low-cost receivers. The nature of the system also allows the effective service areas of transmitters to be controlled.

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Section	Title	Page
	Summary	Title Page
1.	Introduction	1
2.	F.M. signalling and capture effect	1
	2.1. Basic principles	1
	2.2. Practical circuit performance	3
	2.3. Effect of more than one interfering signal	3
	2.4. Suggested modulation parameters of f.m. signalling systems	4
3.	Experiments conducted using the demonstration model	5
4.	Brief field trials	6
5.	The effects of co-channel interference	6
6.	Conclusions	7
7.	References	7
	Appendix A: Capture effect with more than one interfering signal	8
	Appendix B: Possibility of false activation of receivers by remote 'START' signals	9

'CARFAX' TRAFFIC INFORMATION SERVICE: AN ANALYSIS OF THE CHARACTERISTICS OF THE RING SYSTEM AND RECEIVER ACTIVATION

M.J. Kallaway, M.A.

1. Introduction

The original BBC proposal[1] for a Traffic Information Service used an absolute field-strength criterion for receiver activation. If the received field-strength was greater than 3 mV/m during reception of a START code, the receiver would be activated and the message would then be heard. A system relying upon absolute field-strength was later thought to be unsatisfactory in practice, however, due to local variations in field-strength and unavoidable instrumental imperfections in practical receiving systems. The effect of these problems has already been discussed elsewhere.[2,4]

A 'ring system' has now been proposed[2,3,4] which is designed to ensure that the receiver is reliably activated but only by the signals from local transmitters. In the ring system, the receiver responds on the basis of relative, rather than absolute, field-strengths and the method appears to overcome many of the problems encountered when using a fixed field-strength criterion.

In the ring system, the selection by the receiver of the strongest signal from a group of local transmitters is made using the 'f.m. capture effect' in conjunction with an f.m. signalling system. This Report analyses the characteristics of the system.

2. F.M. signalling and capture effect

2.1. Basic principles

In the ring system, the boundary of the service area for a transmitter is determined by deliberate jamming or inhibiting of the START signal which heralds every message. The process is described below.

Fig. 1 shows part of an idealised lattice of transmitters. The transmitter labelled T_0 is the message-carrying transmitter, and the six transmitters, labelled T_1 to T_6, that encircle T_0, are a ring of jamming or inhibiting transmitters associated with T_0. Every transmitter in the lattice can operate as a message transmitter and, when in the message mode, each will use its surrounding transmitters as ring transmitters* operating in the inhibiting or jamming mode.

Fig. 2 shows the sequence of events whenever transmitter T_0 radiates a message. Transmitter T_0 radiates a START signal at the beginning of each message; this consists of a 125 Hz signal which frequency-modulates the carrier with a peak deviation of ±2 kHz. Simultaneously, the encircling ring of transmitters radiates a c.w. signal at reduced power for a somewhat longer period that 'straddles' the START signal from the message transmitter.

Consider a receiver situated at point P in Fig. 1 which will receive its predominant signals from transmitters T_0 and T_1. If the signal from T_0 is stronger than that from T_1, 'f.m. capture effect' will ensure that the f.m. START signal from T_0 is received. Conversely, if the signal from the transmitter T_1 is stronger than that from T_0, capture effect will cause the START signal to be suppressed. With the signal parameters chosen, capture effect is very pronounced, so that a small change in the ratio of the strengths received of the signals from T_0 and T_1 causes a very large change in the level of the demodulated START tone in the receiver.

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* Throughout this Report, the term 'ring transmitter' is used to describe a transmitter operating in the jamming or inhibiting mode and the term 'ring signal' is used to describe the signal transmitted by a ring transmitter.

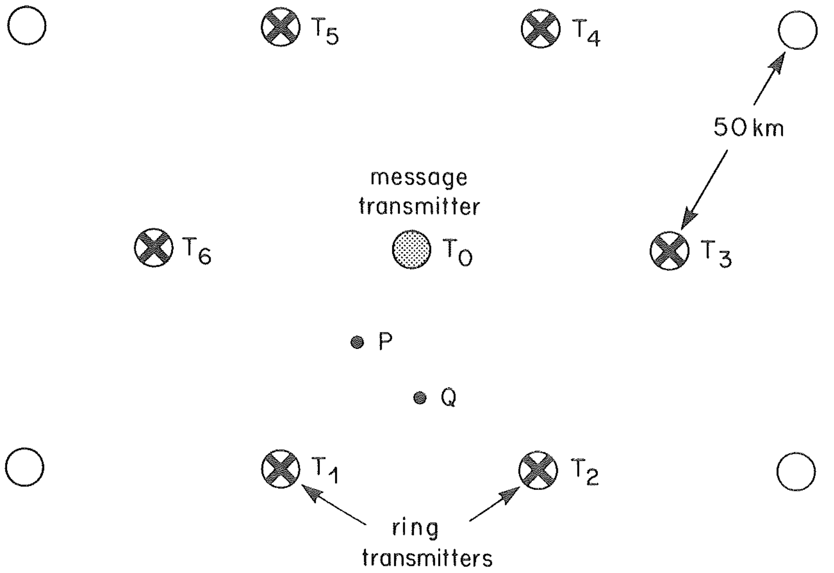

Fig. 1 - Ideal lattice of transmitters

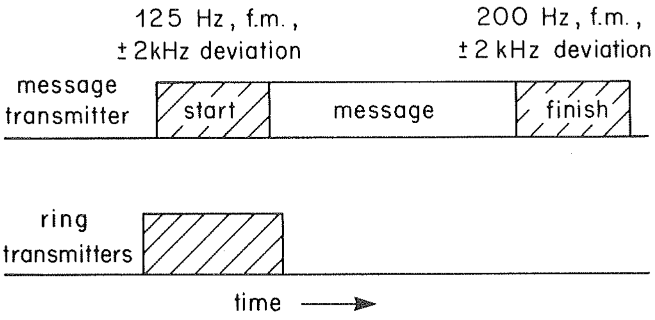
125 Hz, f.m., ± 2kHz deviation
200 Hz, f.m., ± 2 kHz deviation
message transmitter
start
message
finish
ring transmitters
time

Fig. 2 - Sequence of events during operation of ring system

It can be seen from the above that the activation of receivers is determined by the relative field-strengths from the message and ring transmitters. The ring transmitters prevent the START signal from being received beyond a certain range, creating a well-defined limit to the service area of the message transmitter. The extent of the service area can be varied by adjusting the relative powers of the ring transmitters.

A full understanding of capture effect is difficult to achieve without detailed mathematical analysis. A simple explanation is given below using the vector diagrams of Fig. 3; a complete analysis is given in Reference 5.

Fig. 3(*a*) represents a carrier of unit amplitude, frequency-modulated by a START signal. The modulation index of this signal is high, so that the vector of Fig. 3(*a*) completes several revolutions in both clockwise and anti-clockwise directions during each modulation cycle.

Fig. 3(*b*) is similar to Fig. 3(*a*) except that an unmodulated interfering signal of amplitude b ($b<1$) has now been added, thus simulating the effect of a signal from a ring transmitter; the locus of the resultant vector is shown by the circle. If the f.m. carrier makes several revolutions in either direction, the resultant vector will also complete the *same* number of revolutions. Thus a frequency-discriminator fed with the resultant signal would give a demodulated output signal proportional to the rate-of-change of phase of the resultant vector, although this would be non-sinusoidal. However, since in these circumstances the resultant vector completes the same number of revolutions as the f.m. carrier vector, the level of the output fundamental 125 Hz component will be virtually unchanged by the addition of the unmodulated interfering carrier.

Fig. 3(*c*) illustrates the case when the interfering carrier representing the signal from a ring transmitter is stronger than the f.m. carrier ($b>1$). As before, the locus of the resultant vector is shown by the circle. Unlike the case of Fig. 3(*b*), however, the locus of the resultant no longer encloses the origin, 0. Hence, no matter how many revolutions the f.m. carrier vector completes, the resultant vector does not complete even one revolution. Consequently, if the resultant signal is applied to the input of a frequency-discriminator, the level of the demodulated fundamental 125 Hz component will be much lower than before.

Fig. 4 shows the theoretical variation[5] of the level of the fundamental component of the 125 Hz tone output from a f.m. discriminator, as a function of the ratio of the levels of the f.m. carrier and the interfering carrier. The graph is plotted assuming a peak deviation due to the 125 Hz tone of ±2 kHz. These are the parameters of the START signal for the proposed 'CARFAX' Traffic Information Service. The theoretical curve in Fig. 4 shows that, as the carrier ratio changes from 'just greater than unity' to 'just less than unity', the level of the 125 Hz output changes by more than 30 dB; the curve has infinite slope when the carrier ratio is unity.

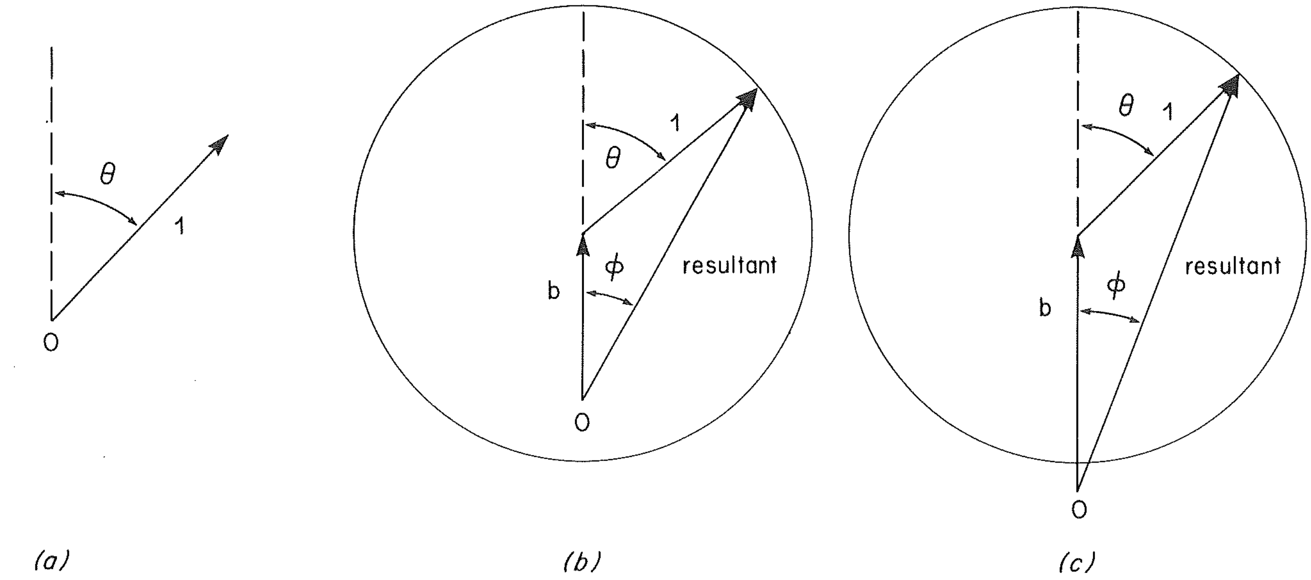

Fig. 3 - Vector diagrams illustrating capture effect

(*a*) f.m. carrier of unit amplitude (*b*) f.m. carrier of unit amplitude and interfering c.w. of amplitude $b(b<1)$
(*c*) f.m. carrier of unit amplitude and interfering c.w. of amplitude $b(b>1)$

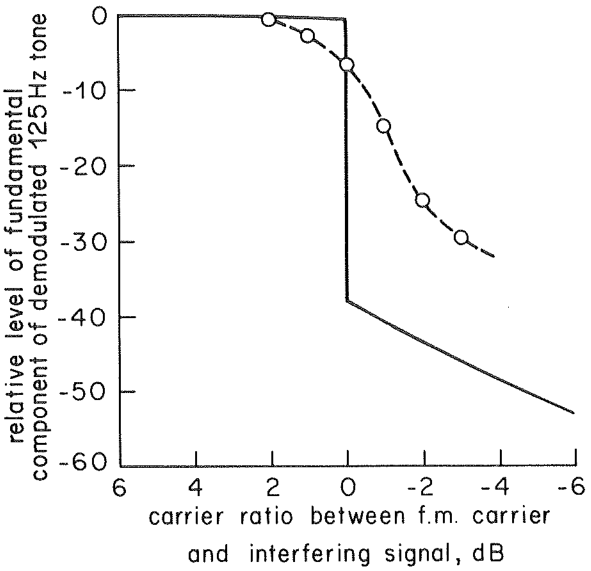

Fig. 4 - Capture effect for f.m. carrier modulated by 125 Hz tone, ±2 kHz peak deviation and a single interfering signal

2.2. Practical circuit performance

In practical systems, capture effect is not as pronounced as shown by the theoretical curve of Fig. 4, the main limitation being imposed by the bandwidth of the f.m. discriminator. Referring to Fig. 3(*c*), it can be seen that the phase of the resultant vector changes very rapidly when ϕ is near 180°. Since the frequency of a signal is equal to its rate-of-change of phase, this corresponds to a very high peak-frequency-deviation; in fact, if b were equal to unity, the peak deviation would be infinite. Examples of signal waveforms under these conditions are given in Reference 6. A practical f.m. discriminator with limited bandwidth will 'clip' at high peak-deviations, causing intermodulation between the various harmonics that make up the output signal. Hence, the level of fundamental component of the 125 Hz START signal will be altered.

The capture effect obtained using a typical integrated-circuit f.m. discriminator is shown in Fig. 4. In this case, the discriminator consisted of a wide-band limiter followed by a simple 'quadrature-coil' detector; the bandwidth of the discriminator was 11 kHz. The experimental results show a less pronounced capture effect than the theoretical results. Even so, a change in carrier of only 4 dB changes the level of the 125 Hz fundamental component by 30 dB.

2.3. Effect of more than one interfering signal

So far, the effect of a single ring signal interfering with an f.m. carrier has been considered. This is representative of the situation, when the receiver is at point P in Fig. 1. However, if it were at Point Q, two interfering ring signals of approximately equal level would be received from transmitters T_1 and T_2; in this case, the capture effect would be less pronounced.

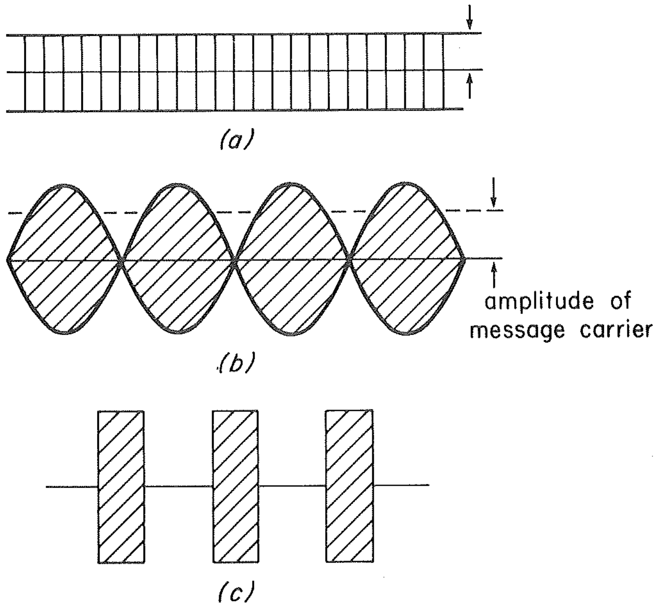

Fig. 5 - Capture effect for two equal amplitude interfering signals

(*a*) Signal from message transmitter
(*b*) Sum of signals from ring transmitters
(*c*) 125 Hz output from f.m. discriminator

The change in capture effect can be seen with reference to Fig. 5. Fig. 5(*a*) represents the signal received from the message transmitter T_0 during transmission of the START signal. Fig. 5(*b*) represents the sum of the signals from the ring transmitters T_1 and T_2; the envelope is modulated at the beat frequency between the two carriers, here shown equal in level. Whenever the envelope of the sum of the two interfering signals exceeds the amplitude of the f.m. carrier from T_0, the receiver will be captured by the combined signal from the ring transmitters. Conversely, whenever the envelope of the sum of the two interfering signals is less than that of the f.m. carrier, the f.m. carrier will capture the receiver and the START signal will be received. The theoretical output from an f.m. discriminator fed with the combined signals would be as shown in Fig. 5(*c*); there would be a series of bursts of 125 Hz tone at full-amplitude. Thus it will be seen that the average level of the tone is linearly related to the percentage of the time that the amplitude of the f.m. carrier exceeds the envelope of the sum of the interfering or inhibiting signals from the ring transmitters.

The effect when more than one signal is received from the ring transmitters is plotted in Fig. 6. The theoretical results are derived in Appendix A, using the theory discussed above, whilst the experimental results were obtained using the same f.m. discriminator as before. The curves of Fig. 6 are plotted for various ratios (X) between the signals from the ring transmitters. It is seen that capture effect is 'diluted' by the presence of more than one signal from the ring transmitters. However, it is interesting to note that all the curves intersect at virtually the same point, when the carrier ratio is about unity. In this, there is close agreement between the theoretical and practical results. So, if the receiver is adjusted to respond to the demodulated START tone whenever its level is greater than

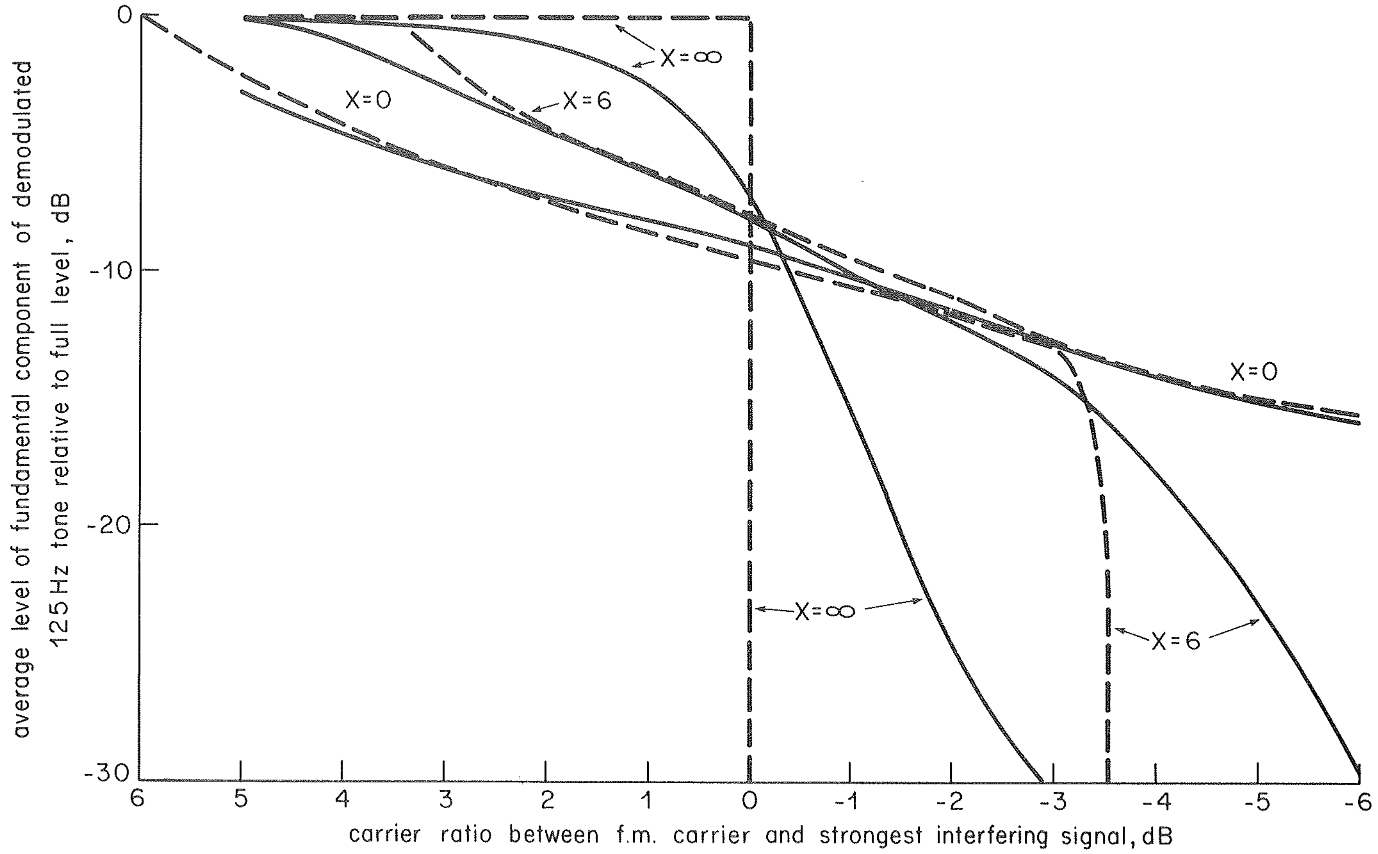

Fig. 6 Capture effect for f.m. carrier modulated by 125 Hz tone, ±2 kHz peak deviation and two interfering signals

▬ ▬ = theoretical curves ▬▬▬ = experimental curves X = carrier ratio between interfering signals, dB

that at the approximate crossover point in Fig. 6, the receiver will always be activated at about the same carrier ratio. This condition can be satisfied if the receiver is set to respond when the START tone is at −8 dB with respect to its full amplitude. A small error in this setting would not seriously alter the carrier ratio threshold.

Despite the limitations discussed above, it is clear that capture effect allows the receiver to determine accurately which is the stronger local signal.

It is important to ensure however, that, when the signals from two ring transmitters are almost equal, the receivers should be able to respond to the *average* level of the received START tone. If the receiver were not able to do this, then it can be seen from Fig. 5(*c*) that any one of the bursts of 125 Hz tone, if of sufficient duration, could activate the receiver, since all are at full amplitude. One way of ensuring that the receiver is able to average the level of the START tone under these circumstances is to frequency-modulate the ring signals with a random noise signal so as to break up the beat between them. Referring to Fig. 5, if the beat between these signals is deliberately made random, then the bursts of 125 Hz tone will also be of random duration. By making a suitable choice of the parameters of the noise modulation (as described in the next section), it is possible virtually to guarantee that no single tone-burst will last long enough to raise the average level sufficiently to activate the receiver; consequently, the receiver will always average the level of the 125 Hz tone. The method has been successfully tested and adopted in practice. (The noise frequency-modulation is applied only when the transmitter is in the ring mode; if it were applied during the message mode it would degrade the signal-to-noise ratio.)

2.4. Suggested modulation parameters of f.m. signalling systems

The originally proposed modulation parameters for the f.m. signalling system are listed below:

1. START signal: 0·5 s burst of 125 Hz tone frequency-modulating the carrier with a peak deviation of ±2 kHz.
2. FINISH signal: 0·5 s burst of 200 Hz tone frequency-modulating the carrier with a peak deviation of ±2 kHz.
3. Ring transmitters: frequency-modulated by low-frequency noise signals with an r.m.s. deviation of 400 Hz and limited in bandwidth to an upper frequency of about 100 Hz.

The above parameters were chosen somewhat arbitrarily. In the case of the START signal, its frequency and deviation were chosen so as to give a high modulation-index and hence a pronounced capture effect.[5] The FINISH signal was then chosen to be easily distinguishable from the START signal. The duration of the bursts of control signal were also chosen arbitrarily and may have to be

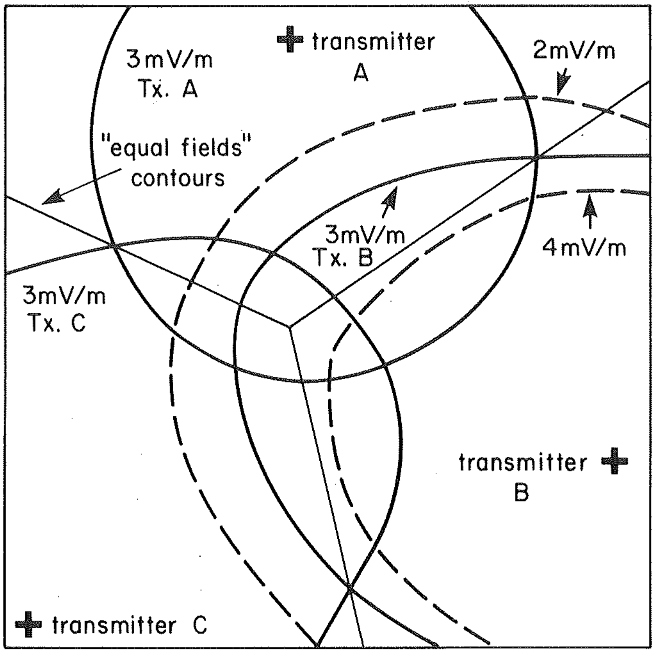

Fig. 7 - Field-strength contours on demonstration model

lengthened for reasons discussed later in Section 4. The noise signal modulation applied to the carrier whilst a transmitter is on the ring mode was chosen to ensure that the receivers would always average the level of the demodulated START signal, as discussed in Section 2.3. The noise signal itself need not be truly Gaussian in character and pseudo-random noise has been found to be acceptable in practice.

3. Experiments conducted using the demonstration model

A demonstration model was designed to show some of the principle features of the proposed traffic information service, and a brief description is given here.

The model operates at carrier frequency and is intended to simulate realistically the broadcasting and reception of signals on m.f. It consists of a board about four feet square covered by a map, underneath which is a sheet of resistive paper that is earthed around its edges by means of a copper strip. An r.f. signal can be injected at three points to simulate three transmitters, small metal contacts being fixed to the resistive paper at these points, the earth returns being connected to the outer copper strip. The signal strength at different points on the model is sensed using a capacitive probe located beneath a 'matchbox' car. Fig. 7 shows how the signal-strength, sensed using this probe, varies for the three transmitters.

Experimental circuits have been built so that the model can operate using the ring system such that, whenever one of the three transmitters carries a message, the other two act as ring transmitters. Although there are only two ring transmitters, rather than six, the model can simulate quite accurately one sector of the service area of any transmitter.

Using the model and a prototype receiver,[7] the service area of each transmitter was plotted, the relative power of each of the ring transmitters having been adjusted so that there was a reasonable overlap between the service areas. Fig. 8 is a photograph of the model showing the measured service areas when the power of the transmitters in the ring mode was 6 dB lower than when in the message mode. From Fig. 8, it is apparent that the complete service area of each transmitter is roughly hexagonal in shape, overlapping the 'equal-fields' contours by an almost constant distance. This is not surprising since activation of the receiver by the START signal depends *only* on the carrier ratio between the signal from the message and ring transmitters.

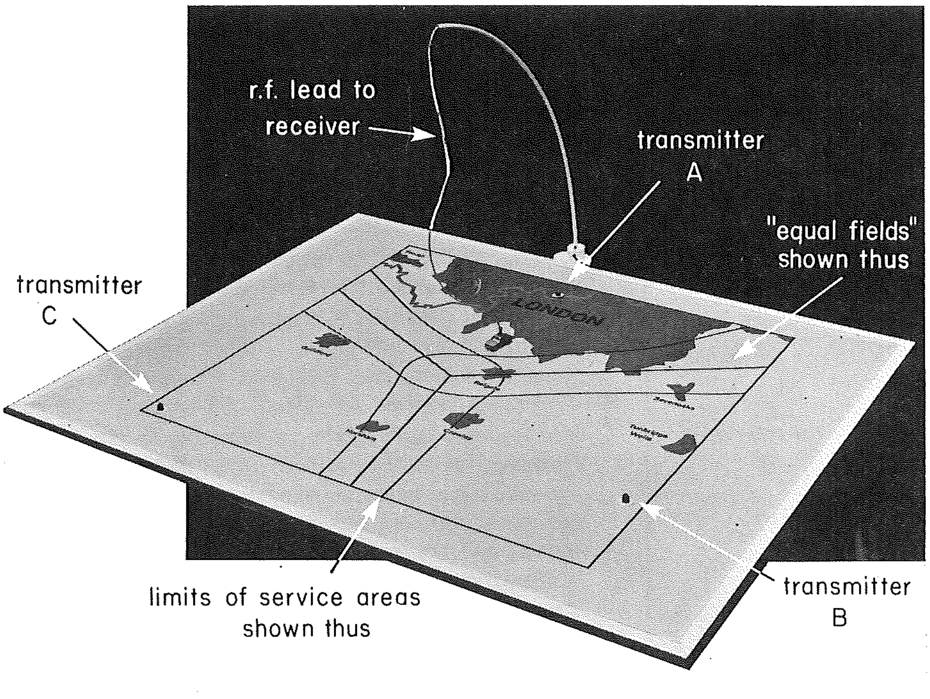

Fig. 8 - Service areas for ring system using f.m. signalling

The model has also been used to study possible ways in which variations in receiver characteristics could vary the shape of the service areas. One parameter that may be sensitive in this way is the level of the demodulated 125 Hz START tone necessary to activate the receiver. Referring to Fig. 6, it can be seen that when the signal from one ring transmitter predominates (i.e. X has a high value), the capture effect is so pronounced that a small change in this operating threshold has little effect on the carrier-ratio at which activation occurs. On the other hand, when there are two equal signals from the ring transmitters a 1 dB change in the threshold corresponds to a 1 dB change in the carrier ratio.

The effect on the service area of variations in the receiver's activation threshold is shown in Fig. 9. The effect is shown only for the service area of Transmitter C; a similar change occurs for the other transmitters. Three curves are shown. The central curve is drawn assuming that the threshold is at the normal level, corresponding to a peak frequency-deviation for the START tone of 800 Hz. This level corresponds to the approximate intercept point of the curves in Fig. 6. The effect of changing this threshold level by ±2 dB is shown by the two other curves in Fig. 9. A change in the receiver threshold level for the START tone is seen to have only a limited effect on the service area. The area where it is at all critical is in the overlap area when all three transmitters give equal field-strengths. Even here, the effect is not great and so it is thought that a ±2 dB spread in receiver operating thresholds could be tolerated, although it is unlikely that this would occur in practical receivers.

4. Brief field trials

The activation of the motorist's receiver is determined by the ratio of the signal-strengths received from the message and ring transmitters. Hence, the system is not sensitive to local field-strength variations that affect all signals equally. However, if signals arriving from different directions are affected differently by local variation, then the service area of each transmitter would be changed.

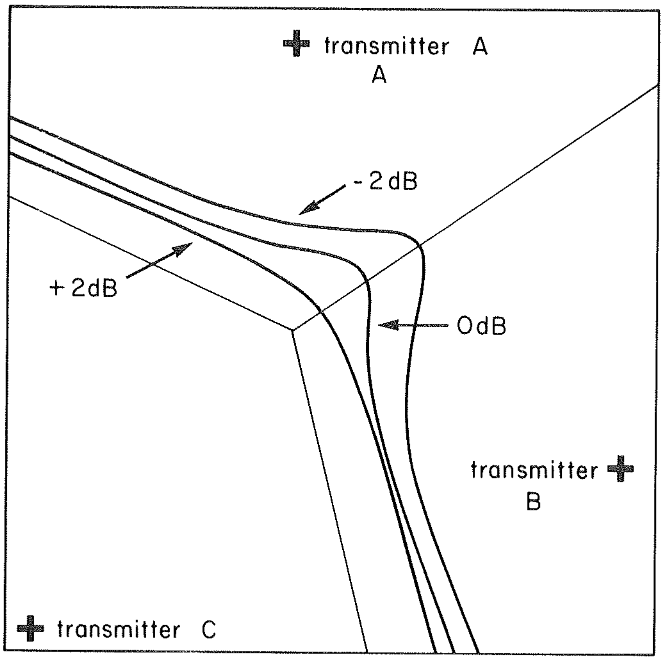

Fig. 9 - Change in service area of Transmitter C for ±2 dB change in receiver's START tone threshold

Recently, measurements have been made of the ratio of signal strengths received in the London area from two 534 kHz transmitters at Brookmans Park and Kingswood Warren. The complete results of this work are given in Reference 8.

It was found that the variation in the ratio of the two received signal strengths at 90% of locations was within 4 dB of the median value for the local area. On rare occasions, the ratio was found to vary over a 10 dB range, and this is thought to be due to the local effects of steel-framed buildings and overhead wires. From this work, it can be concluded that the boundaries between service areas will be somewhat irregular. Fortunately, the necessary requirement of an overlap of adjacent service areas for proper coverage by the traffic information will largely override these effects.

The boundaries of the service areas would be somewhat better defined if the receiver were to average-out some of the local fluctuations in field-strength ratio. Since, in general, the vehicles concerned are in motion, this can be achieved by lengthening the START code and increasing the response time of the receiver. This possibility is currently being considered.*

5. The effects of co-channel interference

The effects of co-channel interference are under separate investigation,[9] and only the forms of interference that affect proper receiver activation and de-activation are considered here. The f.m. coding system is very rugged and can tolerate very high levels of interference without false operation. For example, for a FINISH code from a distant transmitter to de-activate a local receiver during a message, the received field-strength must be greater than that from the local transmitter.

There is, however, one situation in which co-channel interference will affect the performance of the f.m. coding system. This arises when all the local transmitters are switched off and a START signal is received from a distant transmitter. There is then a possibility that the receiver will be falsely activated. This possibility is reduced to some extent by the fact that the START signal from a distant transmitter will always be accompanied by several interfering signals from its associated ring transmitters. However, as will be shown later, the possibility of false activation can never be ruled out since the ring transmitters radiate at reduced power compared to the message transmitter, and sky-wave propagation could favour the message transmitter at some receiving locations. The likelihood of false operation is greater at night and in winter due to higher sky-wave field-strengths.

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* For the reasons given, and also for reasons of receiver design, it is likely that the duration of the START code signal will be increased, perhaps to about 0·8 s.

A brief experiment was conducted to study the possibility of false activation by remote START signals. A signal carrying START code modulation and a number of interfering (ring) signals each of equal level were added together to simulate a signal received from a remote group of transmitters. This signal was applied to the input of a prototype receiver.[7] The level of each of the interfering signals and their numbers were adjusted until the START signal just activated the receiver. Because of the large number of signals forming the composite input signal, the threshold condition was not well-defined and the results were therefore recorded when there was a 50% probability of activation. The results of this experiment are shown in Table 1. Also shown are the results of a theoretical analysis (given in Appendix B), and these agree fairly closely with the practical results.

TABLE 1

Number of interfering ring signals	Level of each interfering (ring) signal, relative to the message signal, for receiver to be activated for 50% of the time	
	Measured	Calculated
6	−5·7 dB	−6·3 dB
4	−4·5 dB	−4·7 dB
3	−3 dB	—

From the results shown in Table 1 it is fairly clear that even six ring transmitters, each with a power relative to the message transmitter of −6 dB,* would not prevent false activation.

However, it is easily possible to protect quiescent areas from distant START signals by using the inhibiting properties of a local transmitter. A single transmitter, on relatively low power, would provide a protective 'blanket' extending over quite a large area. This approach is quite attractive as it is simple to operate and virtually certain to work.

6. Conclusions

A system for activating motorists' 'CARFAX' Traffic Information Service receivers has been described which appears to overcome many of the problems associated with a system relying on absolute field-strengths. The system is designed so that the receiver is activated by only the (strongest) signals from local transmitters. The selection of the strongest signal is achieved by using the f.m. capture effect, so that receiver imperfections do not greatly influence the performance of the system. F.M. signalling tones are inherently rugged and, consequently, the chance of false operation of the receiver is small.

Receivers for this system should be cheap due to the uncritical nature of the required circuitry.

Preliminary field-trials indicate that the system should operate well in practice, although a final verdict must await the results of a larger scale trial.

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* −6 dB is the relative power of a transmitter when in the 'ring' mode necessary to give about the right overlap between service areas.

Appendix A

Capture effect with more than one interfering signal

As discussed in Section 2.3, the average level of the demodulated 125 Hz tone signal depends on the percentage of the time that the amplitude of the f.m. carrier exceeds the envelope of the sum of the signals from the ring transmitters. Assuming that the f.m. discriminator exhibits perfect capture, whenever the envelope of the interfering signals is greater than that of the f.m. carrier, the level of the demodulated 125 Hz tone will be zero. Conversely, whenever the envelope of the interfering signals is less than that of the f.m. carrier, the demodulated 125 Hz tone will have full amplitude. The average level of the demodulated 125 Hz tone is linearly related to the percentage of the time that the f.m. carrier amplitude exceeds the envelope of the signals from the ring transmitters.

For the case of two equal interfering signals, their resultant envelope is given by:

$$\text{envelope of two equal interfering signals} = a\sqrt{2}(1 + \cos\theta)^{\frac{1}{2}} \qquad (1)$$

Where a = amplitude of each interfering signal
θ = instantaneous phase difference between the interfering signals

Let the f.m. carrier have unit amplitude. Therefore, for the f.m. carrier amplitude to exceed the envelope of the two interfering signals:

$$1 > a\sqrt{2}(1 + \cos\theta)^{\frac{1}{2}} \qquad (2)$$

Rearranging

$$\frac{1}{2a^2} - 1 > \cos\theta \qquad (3)$$

For any particular amplitude, a, of the interfering signals there is a range of values of θ which satisfy relation (3). Since all values of θ between 0 and 2π are equally likely, the average level of the demodulated 125 Hz tone is given by:

$$\left.\begin{array}{l}\text{Average level of demodulated}\\ \text{125 Hz tone relative to full}\\ \text{amplitude}\end{array}\right\} = \left\{\frac{\begin{array}{c}\text{range of values of } \theta\\ \text{that satisfy (3)}\end{array}}{2\pi}\right. \qquad (4)$$

By using relation (3) and Equation (4) the average level of the demodulated 125 Hz tone can be calculated for any particular amplitude, a, of the interfering signals. The results of this calculation are listed in Table 2 below and plotted in Fig. 6.

A similar calculation was performed for two interfering signals, one of whose amplitudes was twice that of the other. These results are also plotted in Fig. 6.

TABLE 2

Amplitude 'a' of each interfering signal (relative to unit amplitude f.m. carrier)	Range of values of θ for which f.m. carrier amplitude is greater than envelope of interfering signals	Average level of demodulated 125 Hz tone relative to full amplitude
2·0	151° to 209° = 58°	−15·8 dB
1·5	141° to 219° = 78°	−13·3 dB
1·25	132° to 228° = 96°	−11·6 dB
1·0	120° to 240° = 120°	−9·5 dB
0·75	96° to 264° = 168°	−6·7 dB
0·5	0° to 360° = 360°	−0 dB

Appendix B

Possibility of false activation of receivers by remote 'START' signals

1. General

As discussed in Section 5.1 there is a possibility that receivers will be falsely activated by START signals from remote transmitters. This possibility is greater at night than during the day due to high sky-wave field-strengths.

In this Appendix a theory is described which enables the possibility of false activation by remote START signals to be calculated. This theory can be adapted to take account of virtually any number of ring transmitters with virtually any power.

The theory assumes that for the START signal to activate receivers the amplitude of the f.m. carrier must be 1·5 dB greater than the envelope of the sum of the associated ring signals for 40% of the time. (The allowance of 1·5 dB arises since the limited r.f. bandwidth of the receiver depresses the level of the widely-deviated f.m. carrier by 1·5 dB compared to the level of the interfering ring and signals. The figure of 40% arises since the receiver is normally set to respond to the demodulated 125 Hz START signal when its average level is 40% (−8 dB) of its full amplitude.)

The theory also assumes that the envelope of the sum of a number of interfering ring signals has a Rayleigh[10] distribution; a Rayleigh distribution describes the envelope of narrowband random noise. When the number of signals is very large, this assumption is quite justified but for small number of signals it is only an approximation.

2. Preliminary experiment

In order to test the assumption about the Rayleigh distribution, simple experiments were conducted for the case when there were four and six c.w. interfering ring signals. Ideally, the distribution of the envelope of the interfering signals should have been measured and compared with the Rayleigh distribution. However, practical envelope detectors are inaccurate at low signal levels and a different approach had to be adopted. If a signal is to have an envelope with a Rayleigh distribution it must satisfy two conditions. Firstly, it must have a narrow fractional bandwidth, otherwise the term envelope is misleading. Secondly, the amplitude distribution of the signal itself (not its envelope), must be Gaussian. For the case of the interfering signals, the first condition is complied with. Consequently, if the sum of the interfering signals is found to have a Gaussian distribution, then its envelope must have a Rayleigh distribution.

In the experiment, the summed signals were applied simultaneously to one input of a high-speed level-comparator and a variable d.c. level was applied to the other input. Whenever the instantaneous level of the interfering signals exceeded the d.c. level, the level-comparator's output changed to its '1' state. Whenever the instantaneous level was less than the d.c. level, the comparator's output changed to its '0' state. Hence, by measuring the average level at the output of the level-comparator, the percentage of the time that the interfering signals exceeded the d.c. level was found.

The results of this experiment for four and six c.w. signals are plotted in Figs. 10 and 11 which show clearly that, for the sum of four and six signals, the resultant amplitude distribution is very close to Gaussian. Hence, the envelope of the sum of the interfering ring signals has a distribution close to a Rayleigh distribution.

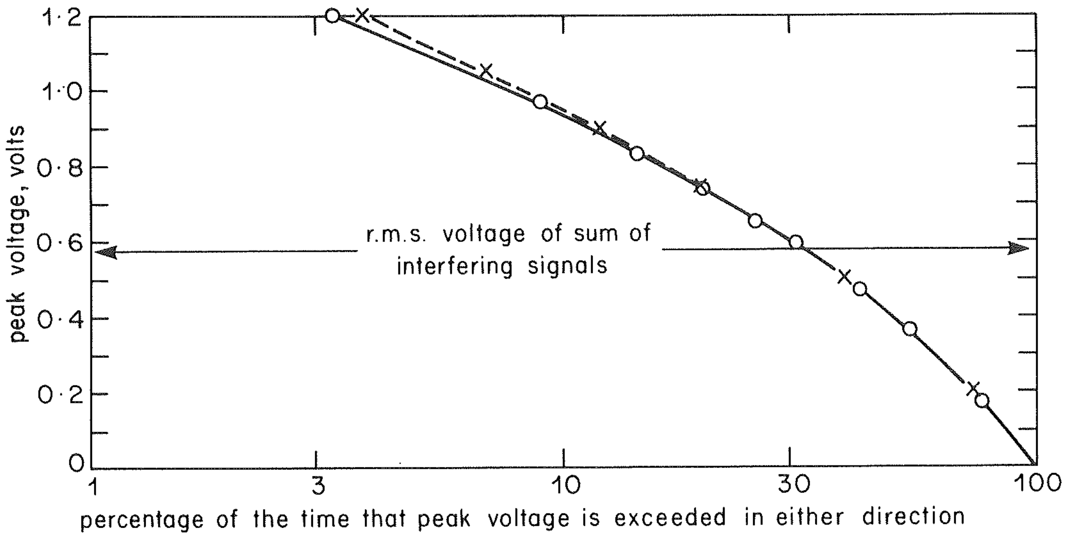

Fig. 10 - Amplitude distribution of four equal amplitude jamming signals

O——O measured distribution X- - -X Gaussian distribution

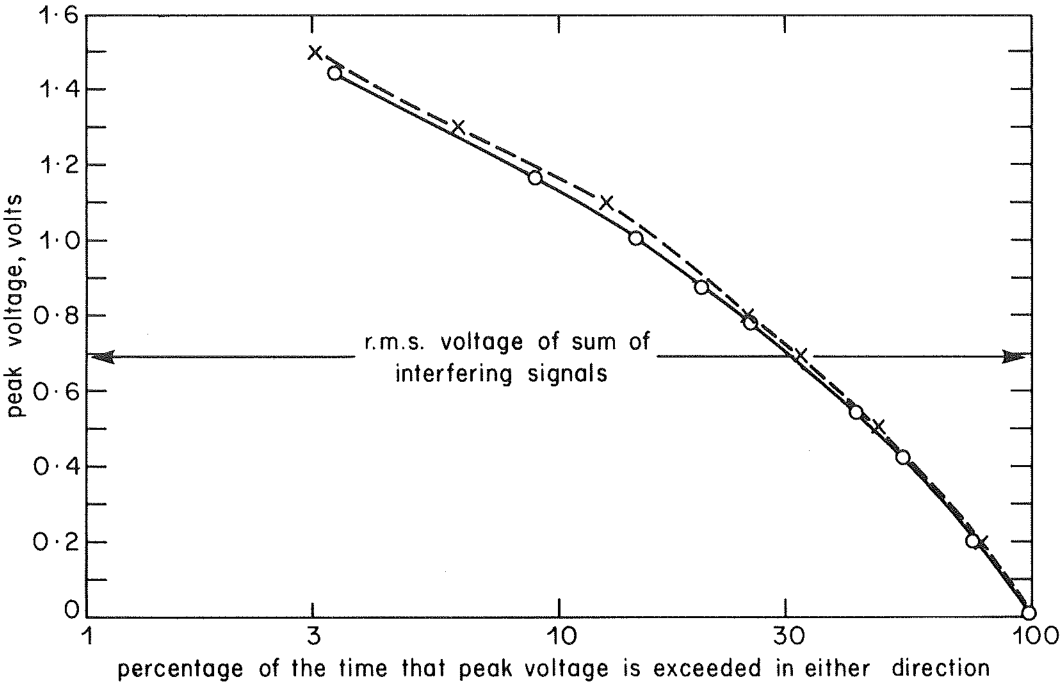

Fig. 11 - Amplitude distribution of six equal amplitude jamming signals

O——O measured distribution X– – –X Gaussian distribution

3. Theoretical calculation

Having confirmed that the envelope of the sum of several interfering ring signals has a Rayleigh distribution, the number of remote ring signals of a given power required to inhibit the associated remote START signal can be calculated.

As stated earlier, for the START signal to activate receivers, the amplitude of the f.m. carrier must be 1·5 dB greater than the envelope of the associated ring signals for 40% of the time. If the f.m. carrier has unit amplitude, then for the START signal to activate receivers:

The envelope of sum of interfering signals must be less than 0·84 for 40% of the time (1)

For a Rayleigh distribution, the probability that the envelope is less than E is given by Reference 10:

$$\text{Probability that envelope is less than E} = 1 - \exp - \frac{E^2}{2\sigma^2} \qquad (2)$$

Where σ = r.m.s. value of the combined interfering signals (not the r.m.s. value of the envelope which is 3 dB greater)

Combining Equations (1) and (2) and solving for σ we get that:

For the START signal to activate the receiver, $\sigma \leqslant 0{\cdot}83$ (3)

This value of σ can result from six interfering ring signals each with an r.m.s. value of less than 0·34 or four inhibiting signals each with an r.m.s. value of less than 0·41.

In other terms, for six signals, their individual powers must be 6·3 dB below the power of the associated message transmitter. Similarly, for four signals their relative powers must be 4·7 dB.

The two powers quoted above will attenuate the level of the demodulated START tone so that its average level will be close to the threshold for activating receivers. Hence, it is reasonable to assume that receivers would be activated for 50% of the time, and protection against this is required as described in Section 5.

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